TITLE: Slot-Antenna Coupled Microbolometer Arrays for THz Radiation

Slot-Antenna Coupled Microbolometer Arrays for THz Radiation

Yoshizumi Yasuoka, Yukihiro Hiraga, and Yasuhiko Abe

Abstract – **New type of slot antenna coupled microbolometer arrays were fabricated, and the receiving properties for 2.5THz-CH_3OH laser radiation were investigated at room temperature. The detected voltage of the device increased in proportion to the number of slots, but the receiving pattern was independent of the number of slots when the slots in the device were arranged with a space of $0.5\lambda_d$ (λ_d: dielectric wavelength).**

I. INTRODUCTION

Recently, the millimeter and submillimeter wave frequency regions have attracted considerable attention as the remaining frequency resource for applications such as communications and remote sensing, and much research has been done to develop electronic devices for realizing these applications. A microbolometer is one of the notable candidates for electronic devices to use in the far-infrared frequency region, because of its room-temperature operation and easy fabrication [1-3].

A conventional bolometer has been used as a thermal detector for infrared radiation, making use of the change of bolometer resistance with an increase in its temperature by absorbing the irradiation power directly or by absorbing the heat power from the radiation absorbers [4]. Therefore, the detection properties strongly depend on the receiving area of the bolometer (size of the bolometer) and the heat capacity of the bolometer including the radiation absorbers. An increase in the size of the bolometer introduces a decrease of the responsivity of the bolometer [5]. The routes of the power absorbed by the antenna coupled microbolometer are different from those of the conventional one. In the case of the antenna coupled microbolometer [1], the irradiation power received by the antenna, then the induced current on the antenna passes through the microbolometer, and finally the resistance of the bolometer changes with the Joule heating. Then, the responsivity of the antenna coupled microbolometer depends on the effective aperture (gain) of the antenna, and is independent of the size of the bolometer (different from the conventional bolometer). In the previous paper, we fabricated a bow-tie antenna coupled microbolometer and receiving properties were investigated at 2.5THz [5]. However, the responsivity was still low.

One of the ways to improve the detection properties of the device is to increase the effective aperture of the antenna by making the antenna array. In this paper, we fabricate a new type of array-coupled with a microbolometer, which is called an antenna-coupled microbolometer array, and investigate the detection properties at 2.5THz. In the new device, each antenna has a microbolometer (for example, the five-antenna coupled microbolometer array has five antennas and five microbolometers), and each bolometer is connected in series.

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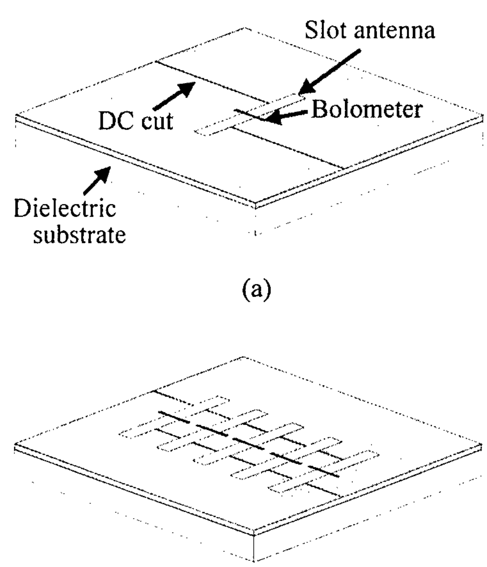
II. CONFIGRATION OF THE SLOT ANTENNA COUPLED MICROBOLOMETER

One of the planar antennas for an antenna coupled microbolometer in the submillimeter wave region is the slot antenna. This slot antenna has a simple configuration and is suitable for microfabrication. Since the radiation is in the direction normal to the substrate, the antenna is suitable for antenna arrays. In addition, since a large grand plane exists, the use of electron beam lithography is possible for fabrication of a microbolometer on the antenna. Figure 1 (a) shows the configuration of the single slot antenna coupled microbolometer. The microbolometer is placed in the center of the slot which is the feeding point. DC cuts (narrow slit lines) are made on the ground plane for supplying DC bias and DC output terminals. Figure 1(b) shows the configuration of the slot-antenna coupled microbolometer array. By placing each bolometer in series, we anticipated that the detected voltage would increase in proportion to the number of slots.



(a)

(b)

Fig.1 Structure of the slot antenna coupled microbolometer.

Figure 2 shows the configuration and equivalent circuits of the slot antenna coupled microbolometer array. When the millimeter or submillimeter wave is irradiated

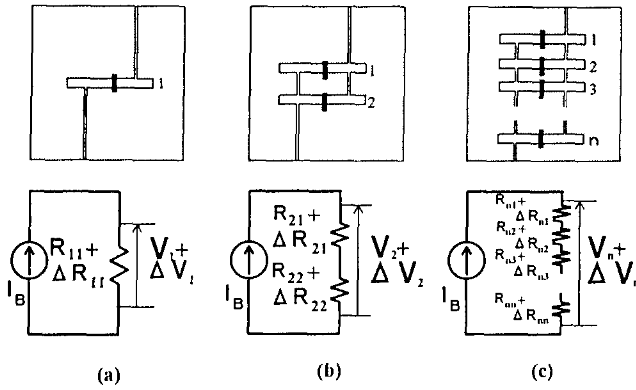


Fig.2 Configuration and equivalent circuits of the slot antenna coupled microbolometer array.

to a single slot antenna coupled microbolometer as shown in fig. 2(a), the power received by the antenna is supplied to the bolometer, and the resistance (R_{11}) of the bolometer changes into $R_{11}+\Delta R_{11}$. The voltage (V_1), which is generated by the bias current (I_b), of the bolometer changes into $V_1+\Delta V_1$. The detected voltage is shown by

$$\Delta V_1 = I_B \cdot \Delta R_{11} = I_B \cdot \frac{dR}{dT} \cdot \frac{dT}{dP} \cdot P_{11} \qquad (1)$$

where dR/dT is the slope of resistance as a function of temperature, and dT/dP is the thermal resistance. Both depend on the material and shape of the microbolometer. P_{11} is the power supplied to the microbolometer from the antenna. In the case of a two slot antenna coupled microbolometers placed in series as shown in Fig. 2(b), the detected voltage (ΔV_2) is written as follows,

$$\Delta V_2 = I_B \cdot (\Delta R_{21} + \Delta R_{22}) \qquad (2)$$

If the bolometer's characteristics are the same for each slot, then equation(2) leads to

$$\Delta V_2 = I_B \cdot \frac{dR}{dT} \cdot \frac{dT}{dP} \cdot (P_{21} + P_{22}) \qquad (3)$$

and the detected voltage of the slot antenna coupled microbolometer *n*-array as shown in Fig. 2(c) is written as

$$\Delta V_n = I_B \cdot (\Delta R_{n1} + \Delta R_{n2} + \cdots + \Delta R_{nn})$$
$$= I_B \cdot \frac{dR}{dT} \cdot \frac{dT}{dP} \cdot (P_{n1} + P_{n2} + \cdots + P_{nn}) \qquad (4)$$

The power $P_{n1} \sim P_{nn}$ supplied to each bolometer in equation (4) are generally dependent on each antenna gain. Each antenna's gain is affected by the reciprocity of other antennas in the array, so there is the possibility that each antenna's gain can become a different value. Therefore, it is necessary to investigate the receiving properties of the slot antenna array, such as its receiving pattern and antenna gain, when we fabricate the slot antenna coupled microbolometer arrays.

III. EXPERIMENTS IN THE MICROWAVE REGION

In order to see the interaction between the slots in a slot antenna c upled microbolometer array, the antenna pattern and the power gain were observed as functions of the space between the slots and the number of slots. The experiments were carried out at 4.7GHz. Each slot array

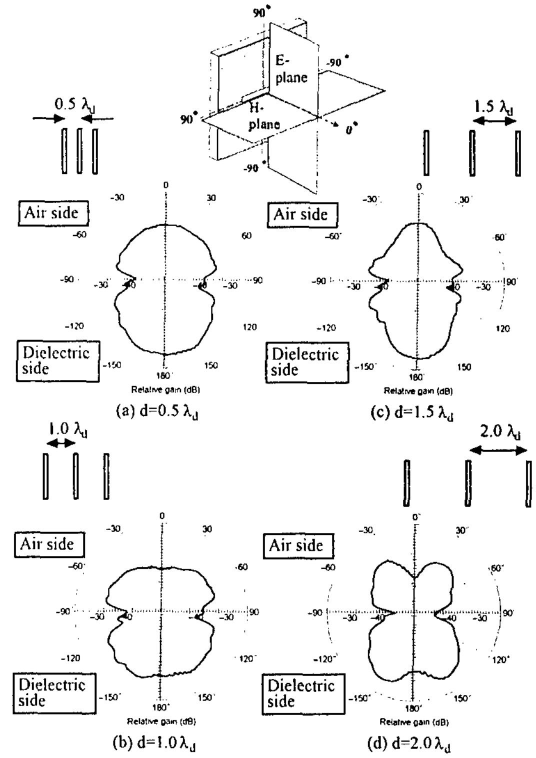


Fig.3 The receiving patterns of the three-slot array at 4.7GHz. The separation of the slots "d" was changed.

element was connected by semi-rigid cable, and the receiving signal was measured using this cable. The relative dielectric constant of the substrate was $\varepsilon_r=4.5$. The length and width of the slots were 0.72 and $0.08\lambda_m$, respectively, in order to operate as a one wavelength slot antenna with impedance 50 Ω [6], where λ_m is the mean wavelength [7] shown by $\lambda_m = \lambda_0/\{(\varepsilon_r+1)/2\}^{1/2}$ in terms of the free space wavelength λ_0. Each slot was loaded with a resistance of 50Ω instead of the bolometer.

Figure 3 shows the E-plane pattern of the three-slot array for 4.7GHz radiation. The patterns are the sum of the measurements obtained by three slots. The distance between the slots (d) was changed from $0.5\lambda_d$ to $2.0\lambda_d$ by $0.5\lambda_d$ step, where λ_d is the wavelength in the dielectric substrate given by $\lambda_d = \lambda_0/\varepsilon_r^{1/2}$. Figure 3 shows that the antenna pattern obtained from the three-slot array was received by the different interactions from the space between the slots. The antenna patterns shown in figs. 3(a) and (c) are more suitable for our purpose than the ones shown in figs. 3(b) and (d), because the antenna patterns shown in figs. 3(b) and (d) have a dent in the direction perpendicular to the substrate. Figures 3(a) and (c) show that the three-slot array arranged with a space of $1.5\lambda_d$ has a receiving power 1dB higher than that of the three-slot array arranged with a space of $0.5\lambda_d$ at a perpendicular angle to the substrate. However, if we rearrange the slots with a space of $0.5\lambda_d$ using the same area as the three-slot array arranged with a space of $1.5\lambda_d$, then we can include seven slots in the same space. The seven slot array arranged with a space of $0.5\lambda_d$ has a receiving power 3dB higher than that of the three-slot array arranged with a space of $1.5\lambda_d$. These facts shows that the suitable space between the slots for our purpose is $0.5\lambda_d$.

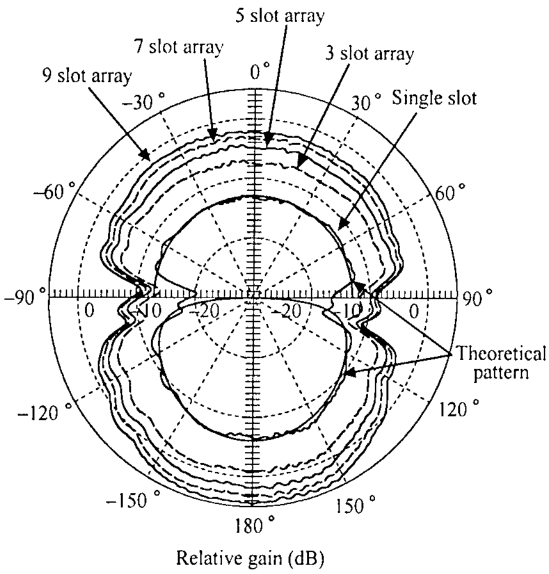


Fig.4 E-plane patterns of slot array at 4.7GHz.

Figure 4 shows E-plane patterns of the single slot and n-slot arrays (n=1, 2, 3, 4, 5, 6, 7, 8 and 9) arranged with a space of $0.5\lambda_d$. In the figure, the theoretical pattern of a single slot antenna is also shown for comparison. From this figure, it became clear that the receiving power increased with an increase in the number of slots, however the pattern is independent of the number of slot as long as the slots are arranged with a space of $0.5\lambda_d$.

IV. RECEIVING PROPERTIES OF THE SLOT ANTENNA COUPLED MICROBOLOMETER ARRAYS

The slot antenna coupled microbolometers were fabricated using microfabrication techniques. The fabrication process is shown in fig. 5. Following completion of the fabrication process, Cr and Au were evaporated on the fused quartz substrate [(a),(b)], and positive electron beam resist was spin-coated on the substrate (c). The shape of the antennas was formed using an electron beam lithographic method (d). The areas of the Au and Cr film not covered with the resist were removed by dry etching (e). Removing the resist completed the antenna part of the process [(f), (g)]. The shape of the bolometer was formed using a photolithographic method [(h), (i)]. Then Bi, which is the material of the bolometer, was evaporated on this resist (j). Finally, the resist was lifted-off to complete the slot antenna coupled microbolometer array (k). Figure 6 shows the SEM photograph of the fabricated 15-slot antenna coupled microbolometer array detector for 2.5THz-CH_3OH laser radiation. The length and width of the slots are 85μm and 10μm.

Figure 7 shows the schematic diagram of the measuring system at 2.5THz. The fabricated slot antenna coupled microbolometer array was placed on a rotating stage, and the bolometer was biased with a current source. A CH_3OH laser was used as a 2.5THz submillimeter wave source. The laser beam was mechanically chopped at 1KHz and radiated to the slot antenna coupled microbolometer array. The detected voltage of the slot antenna coupled microbolometer array was measured with a lock-in amplifier by changing the angle of

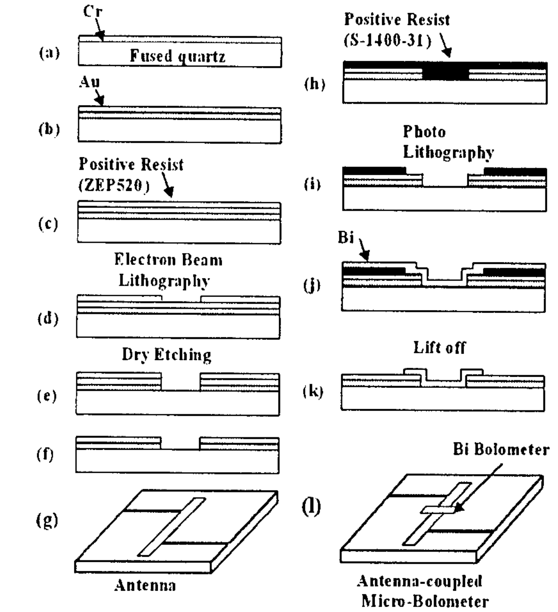


Fig.5 Fabrication process.

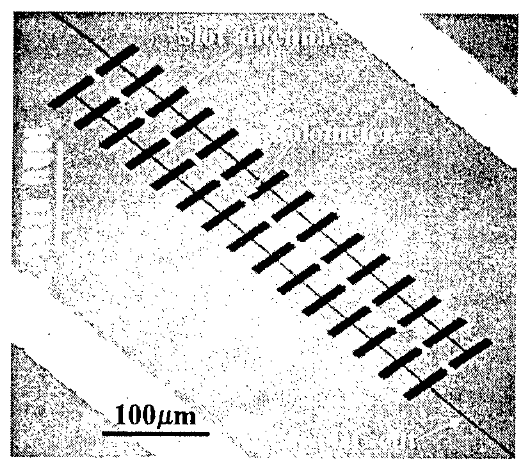


Fig.6 SEM photograph of the fabricated slot antenna coupled microbolometer array for 2.5THz-CH_3OH laser radiation.

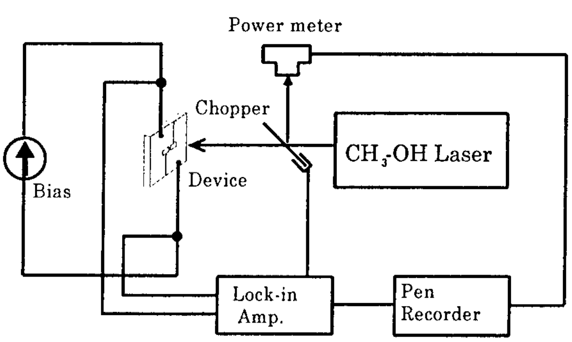


Fig.7 Measurement system for 2.5THz-CH3OH laser radiation.

incidence.

Figure 8 shows the receiving patterns of the seven-slot antenna coupled microbolometer array using 2.5THz-CH_3OH laser radiation. The laser beam was irradiated from the air side. The symbols ● and ○ show the E- and H-plane experimental patterns, and the broken and the solid curves show the E- and H-plane theoretical antenna patterns of a single slot antenna. The experimental data of the seven-slot antenna coupled microbolometer array

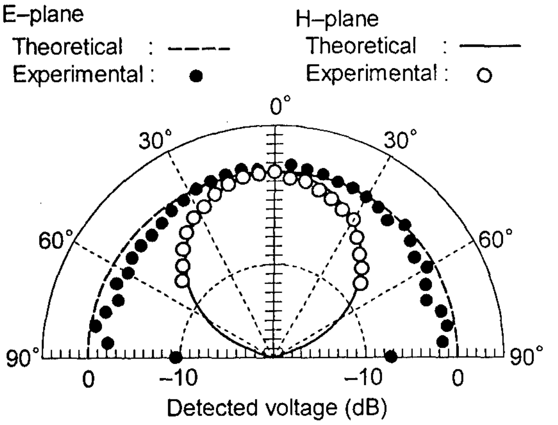


Fig.8 Receiving pattern of the seven-slot antenna coupled microbolometer array, when irradiating a 2.5THz-CH_3OH laser radiation from the air side.

agree with the theoretical antenna pattern of the single slot antenna. From fig. 8, it is found that the receiving patterns of the slot antenna coupled microbolometer array are independent of the number of slots, and are the same as the receiving antenna patterns of the single slot antenna as expected from the results obtained at the microwave band.

The relationship between the number of slots and the detected voltage of the one-dimensional slot antenna arrays is shown by the symbol ● in Fig. 9. The detected voltages increased in proportion to the number of slots. In the figure, the detected voltages of a two-dimensional 5 × 3 slot antenna coupled microbolometer array and a two-dimensional 6 × 3 slot antenna coupled microbolometer array are shown by the symbol △. Figure 9 shows that the detected voltage increases in proportion to the number to slots regardless of the dimension of the arrangement.

V. Conclusion

In order to improve the detection sensitivity of far-infrared radiation detectors, a new type of slot antenna coupled microbolometer arrays was fabricated. The antenna and detection properties were investigated at 4.7GHz and 2.5THz, and the following results were obtained:

(1) The optimum distance between the slots in the slot antenna coupled microbolometer array is $0.5\lambda_d$ (λ_d: dielectric wavelength).

(2) The detected voltage of the slot antenna coupled microbolometer array increased in proportion to the number of slots.

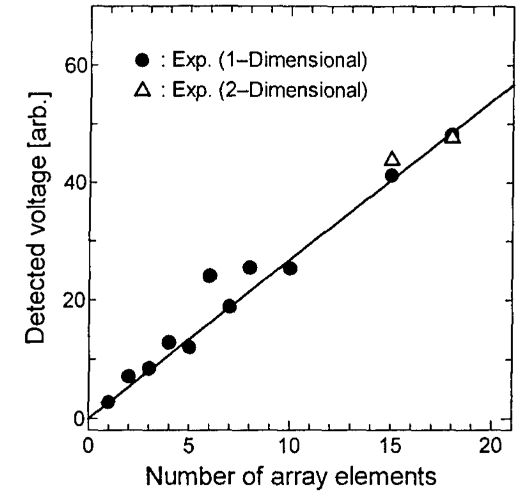


Fig.9 Relationship between number of slots and the detected voltage of the slot antenna coupled microbolometer arrays at 2.5THz.

(3) The receiving pattern of the slot antenna coupled microbolometer array was the same as the antenna pattern of the single slot antenna, and independent of the number of slots.

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